Smart Thermal Environmental and Noise Monitoring to Enhance Indoor Comfort for Classrooms: A Case Study at the International College of Auckland, New Zealand

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Abstract: - The increasing concern about worldwide climate change will necessitate better approaches to daily life. As a result, indoor thermal comfort and air quality in school classrooms have become a global priority to improve air quality in educational settings. In this paper, indoor air quality parameters and noise levels were studied and monitored using an Arduino Uno R3, equipped with a sound sensor, CO_2 sensor, and environmental and humidity sensors to control indoor quality. The performance of the smart thermal environmental and noise monitoring system was evaluated in a typical classroom at the International College of Auckland (ICA) in New Zealand. Mechanical analyses were conducted using HAP software for the classroom, showing that the room requires a 2-ton ceiling air conditioning unit. Parameters were monitered effectivelly, and the hardware controlled the indoor colling system well. The results demondtrated high efficiency and reliable performance for the sensors.

Key-Words: - thermal comfort, indoor quality, humidity sensor, CO_2 Sensor, noise sensor, ICA college classroom.

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1 Introduction

Designing optimal learning environments is essential for fostering student success. Factors such as air quality, thermal comfort, and noise levels significantly impact students' concentration, performance, and overall well-being in the classroom. To establish these ideal conditions, a strategic approach to the design and management of heating, ventilation, and air conditioning (HVAC) systems is necessary, along with soundproofing measures to minimize both external and internal noise disturbances. This will ultimately improve the overall learning environment and experience, [1].

The air quality and indoor thermal comfort in school classrooms are of universal importance due to impact on students' academic performance, health, and overall productivity. Poor air quality and high temperatures present many challenges in school classrooms, especially that students spend a large part of their day indoors. These issues increased when the ventilation rates are insufficient to remove the excessive pollutants and heat, especially when the doors or windows are closed to avoid the noise or adverse weather, [2].

the monitoring of indoor air quality and thermal comfort in the classrooms can be set by measuring various parameters. In the literature review on smart control systems, A variety and wide range of air quality and thermal comfort indicators has been studied and investigated, [3], [4].

The carbon dioxide (CO_2), temperature, relative humidity (RH), and concentration of pollutants such as PM 2.5, are the parameters most frequently studied, [5].

Temperature and relative humidity are crucial for ensuring thermal comfort in classrooms. The American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) recommends a temperature range from 20.3 - 23.8 ^oC in the winter and from 23.8 – 27^oC in the summer, [6]. The recommended RH range for indoor environments is typically between 30% and 60% to prevent mold growth and maintain occupant comfort, [7].

Carbon dioxide (CO_2) concentration is a most of parameter studied and examined for assessing IAQ in classrooms. Elevated CO_2 levels can indicate inadequate ventilation, leading to poor air quality and decreased cognitive performance. Research has shown that the level of CO_2 in classrooms can increase to very high levels due to inadequate ventilation rates, [8], [9]. [10], found that Schoolchildren exposed to CO_2 levels above 1000 ppm face a significantly higher risk for dry cough and rhinitis. It is generally assumed that the higher the CO_2 concentration, the poorer the air quality (less dilution). Although CO_2 has frequently been used to characterize air quality in classrooms, some research has focused on specific pollutants such as particulate matter or contaminants with outdoor sources, [11], [12], [13], [14].

Smart technology has revolutionized the management of indoor air quality (IAQ) by providing innovative solutions that enhance comfort and health in various indoor environments. With the advent of smart sensors and IoT (Internet of Things) devices, real-time monitoring of IAQ parameters, such as carbon dioxide (CO_2) levels, particulate matter ($PM_{2.5}$), humidity, and volatile organic compounds (VOCs), has become more accessible and efficient. These devices consistently collect data and deliver actionable insights, allowing ventilation systems to be modified to ensure optimal air quality.

In recent years, the implementation of advanced control systems for monitoring and managing indoor air quality (IAQ) in classrooms has gained considerable focus. These control systems are engineered to continuously assess, analyze, and manage air quality metrics, ensuring a healthy and effective learning environment. They usually integrate various sensors, data processing units, and actuators to sustain optimal indoor air quality (IAQ) levels. After gathering data from the sensors, the information is processed and analyzed to evaluate the current indoor air quality (IAQ) status and forecast future conditions. [15], carried out research examining the effects of indoor air quality (IAQ) control systems in schools. The findings indicated that automated systems, which adjusted ventilation according to real-time data, were more effective at enhancing IAQ compared to manual approaches. The study also emphasized the energy savings realized through intelligent control strategies that effectively balance IAQ and energy efficiency. Studies have shown that control systems significantly improve Indoor air quality (IAQ) in classrooms, resulting in improved student performance and fewer health-related problems, [16].

The aim of the paper is to design and develop a smart thermal environmental and noise monitoring prototype for a typical NZ classroom, case study International College of Auckland classroom as shown in Figure 1. The HVAC system's sensible and latent loads, airflow, and various other parameters were examined using HAP software to evaluate temperature, pressure, humidity, gas exchange, and acoustic modelling for the developed prototype. This study conducted an in-depth assessment of classroom environments by simultaneously evaluating indoor thermal comfort, air quality, and noise control. It examines the combined impact of HVAC performance on both thermal comfort and noise reduction, providing valuable insights for enhancing classroom design and creating more effective learning spaces.

Fig. 1: Typical International College of Auckland classroom

2 Materials and Methods

2.1 Classroom Size and Parameters

The typical international classroom size and parameters are shown in Figure 2 and Table 1.

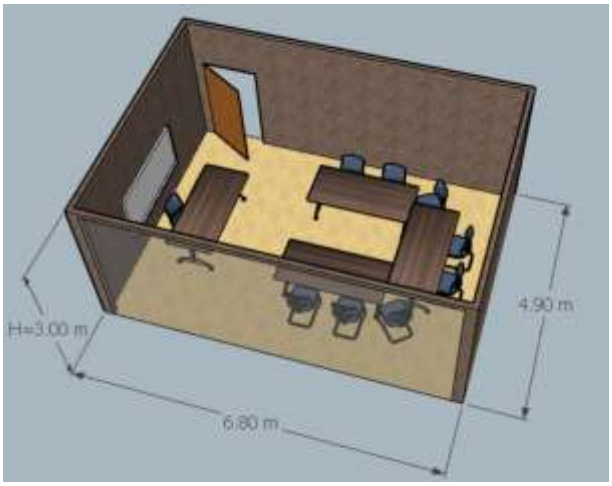

Fig. 2: Classroom Size

As seen in Figure 2 the classroom size is 6.4 m x 4.9 m x 3 m. The classroom features one door, one window, a floor, a roof, and walls. The dimensions of each of these components are provided in Table 1.

Table 1. Classroom Parameters

Room Parameters	QTY	Size m*m
Door	1	1.5*2
Window	1	3*6.5
Floor	1	4.9*6.8
Roof	1	4.9*6.8
Sidewall	2	3*4.9
Front wall	1	3*6.8

2.2 Mechanical Analysis

The analysis of the Heating, Ventilation, and Air Conditioning (HVAC) system for a typical classroom at the International College of Auckland was analyzed using HAP software (Hourly Analysis Program). The analysis focuses on important factors, such as sensible and latent heat loads, airflow, and cooling capacity, to ensure ideal indoor conditions. The overall thermal load of the classroom was computed, encompassing two primary components:

1. **Sensible heat load**: The energy required to cool the classroom air to the target temperature.
2. **Latent heat load**: The energy needed to control moisture levels (humidity) within the classroom.

The thermal performance of the classroom was calculated based on several factors of environmental, including equipment, occupancy, and outside weather conditions. These analyses enable HVAC professionals to calculate the necessary airflow to maintain the desired temperatures and conditions in an ICA classroom.

The heat transfer rate can be calculated as:

$$\frac{Q}{t} = \rho V c \frac{\Delta T}{t} \tag{1}$$

where $(\frac{Q}{t})$ is the heat transfer rate, ρ is the density, V is the volume, c is the specific heat capacity, ΔT is the temperature change, and t is the time over which the heat transfer occurs.

And to convert the equation 1 to cubic feet per minute (cfm) by integrating constants for air density and specific heat capacity. The equation 1 will be:

$$\frac{\mathrm{Q}}{\mathrm{t}} = 1.08 \times \mathrm{cfm} \times \Delta\mathrm{T} \tag{2}$$

and to determine the required airflow (cfm) for heating or cooling, the following equation 3 is used:

$$\mathrm{cfm} = \frac{\frac{\mathrm{Q}}{\mathrm{t}}}{1.08\Delta\mathrm{T}} \tag{3}$$

To fully understand the Sound Pressure Level (SPL), it's important to first grasp the concept of 'Sound Pressure. Sound pressure (p) is the average variation in atmospheric pressure caused by the sound. The unit of pressure measurement is the pascal (Pa). The term 'sound pressure' can be accompanied by other noise measurement terms such as 'instantaneous', 'maximum', and 'peak' (e.g., peak sound pressure). Sound pressure level (SPL) is the pressure level of a sound, measured in decibels (dB). The SPL is the ratio of the absolute sound pressure against a reference level of sound in the air. The SPL can be expressed as:

$$\mathrm{SPL} = 20\log_{10}\frac{\mathrm{p_{RMS}}}{\mathrm{p_{ref}}} \tag{4}$$

where:

- $\mathrm{p_{RMS}}$ is the root mean square of the sound pressure.
- $\mathrm{p_{ref}}$ is the reference sound pressure (0.00002 Pa).

2.3 Prototype Design

A smart thermal environmental and noise monitoring and control system consists of environmental, humidity, CO_2, and noise sensors with an Arduino microcontroller system. Figure 3 shows the developed system, while Figure 4 shows the final smart thermal environmental and noise monitoring system.

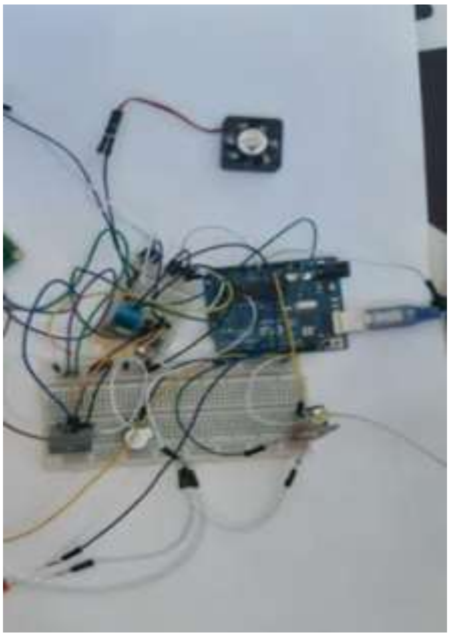

Fig. 3: Prototype fabrication

The smart thermal environmental and noise system components and types are given in Table 2.

The developed system used the Arduino UNO R03 as a microcontroller and the inputs are sound, CO_2, environmental, and humidity sensors, while the outputs are a cooling fan and LED as shown in Figure 5.

Table 2. System Components and Types

Component	Applications
BMP180 sensor	Used to monitor the temperature
DHT11 sensor	Used to monitor the humidity
CCS811 sensor	Used to monitor the CO_2 level
Sound sensor	Used to monitor the noise
Arduino UNOR03	Used as a microcontroller
LEDs	Used to indicate different sound levels
Cooling fan	
Buzzer	

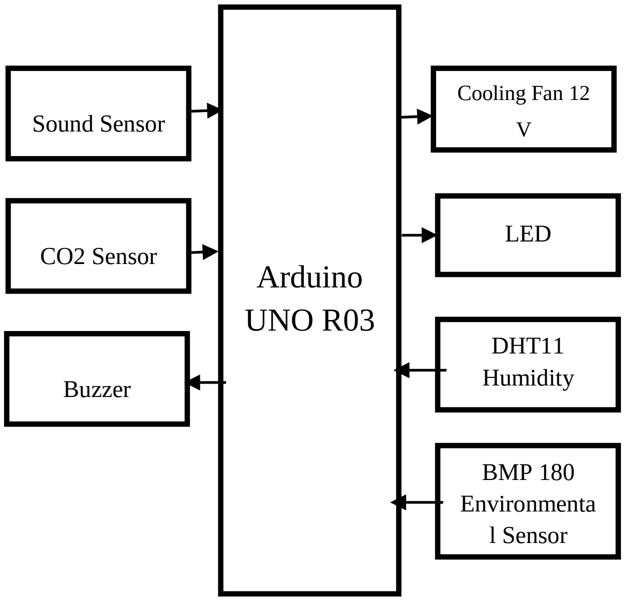

Fig. 5: The developed control system block diagram

2.4 Circuit Diagram

Figure 6 displays the circuit diagram of the smart thermal environmental and noise monitoring system.

Libraries for CCS811, BMP180, and DHT11 sensors were added to the Arduino IDE. Components were assigned to specific pins on the Arduino UNO R03. The setup initialized each component and the loop function read and monitored sensor results. Based on the readings, actions were taken, such as running a cooling fan if the temperature exceeded a certain threshold or activating a buzzer if CO_2 levels were too high. LEDs were used to indicate different sound levels.

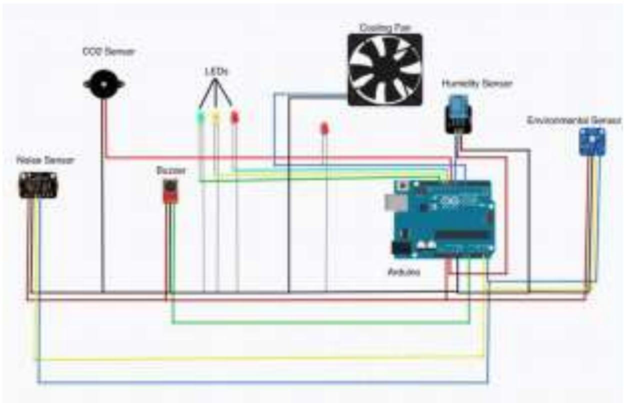

Fig. 6: Smart thermal environmental and noise monitoring system circuit diagram

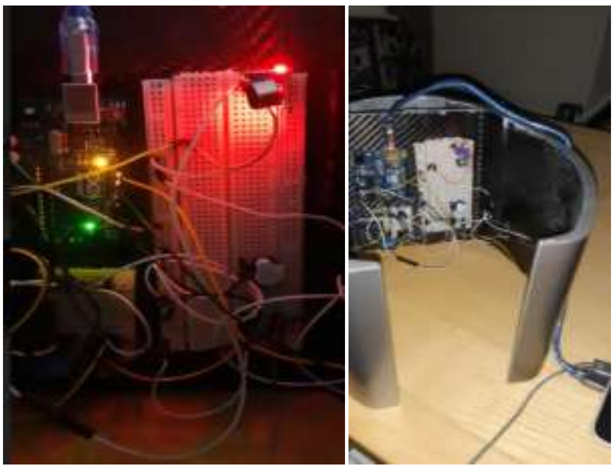

Fig. 4: Final developed system prototype

3 Results and Discussions

3.1 HAP Results for a Typical ICA Classroom

Figure 7 provides a detailed summary of the air system sizing necessary to meet the heating and cooling requirements of the ICA classroom. It includes calculations for airflow rates and equipment sizing to ensure an optimal learning environment.

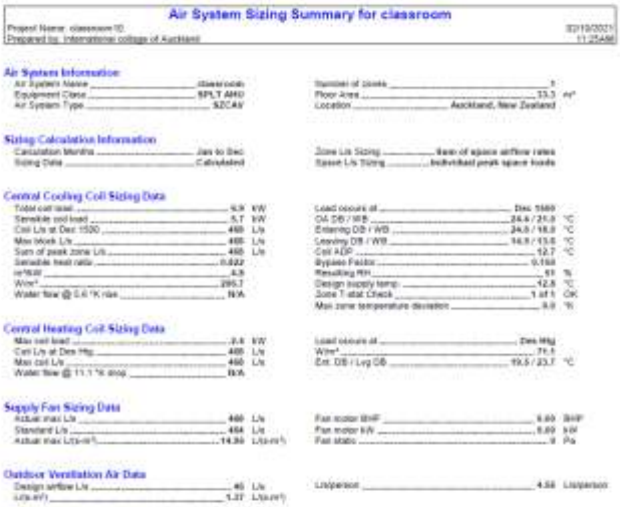
Air System Sizing Summary for classroom

Fig. 7: Air system sizing summary for ICA classroom

The details of the heating and cooling loads calculated for the ICA classroom are shown in Figure 8. It includes data on the thermal energy required to maintain the desired indoor temperature throughout different seasons. Figure 9 presents a comprehensive load calculation, breaking down the various components contributing to the total HVAC load. It covers sensible and latent heat gains and losses, factoring in the occupancy, equipment, and building envelope characteristics.

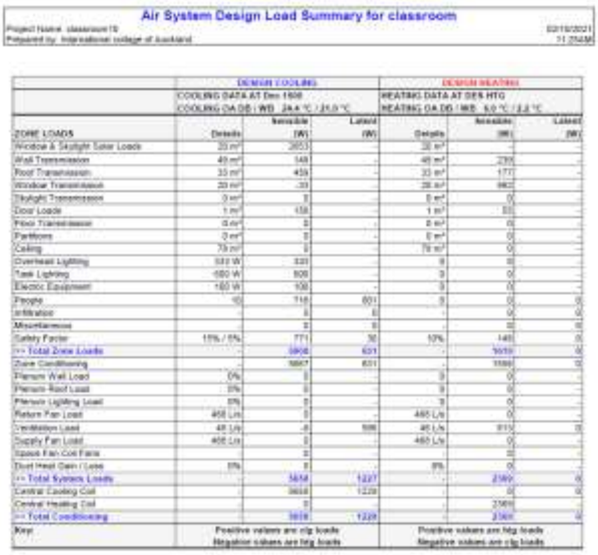
Air System Design Load Summary for classroom

Fig. 8: Air system design load for ICA classroom

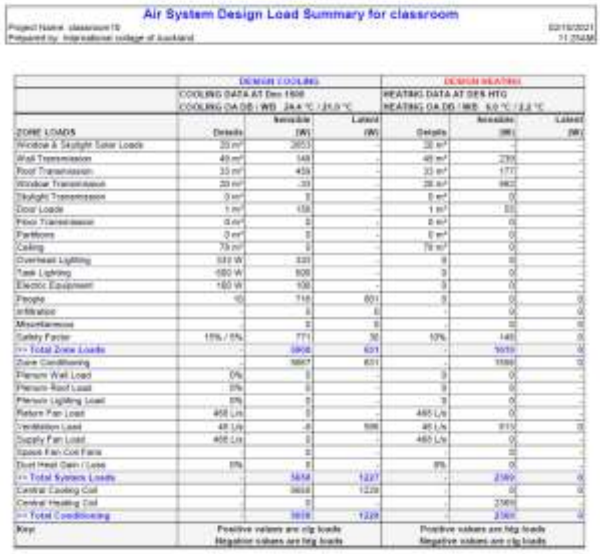
Air System Design Load Summary for classroom

Fig. 9: HAP results for ICA classroom

Figure 7, Figure 8 and Figure 9 illustrate the detailed mechanical analysis, providing insights into the heating, ventilation, and air conditioning requirements for the ICA classroom. The HAP software helps in accurately determining these parameters to ensure a comfortable and efficient environment. From the HAP analysis, the classroom's total sensible heat load was calculated to be 18,000 BTU/hr, while the latent heat load (accounting for moisture control) was approximately 6000 BTU/hr, resulting in a total cooling requirement of 24,000 BTU/hr, or 2 tons of cooling capacity.

3.2 The Smart Thermal Environmental and Noise Monitoring System Results

Figure 10 shows the results of temperature readings from the BMP180 sensor. As seen from the figure temperature readings fluctuate between 22.5 and 25.8 degrees Celsius. When the temperature exceeded 25.5 degrees, the cooling fan was activated.

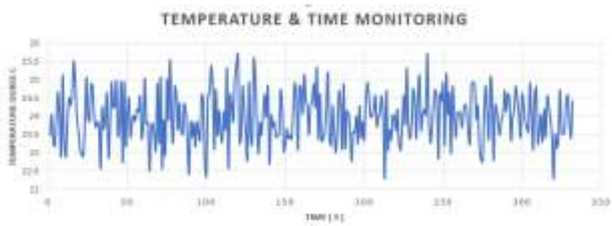

Fig. 10: Temperature & time monitoring result

For humidity monitoring inside the ICA classroom, the DHT11 sensor indicated the classroom humidity was between 50 and 60%, showing good indoor air quality (Figure 11).

Fig. 11: Humidity and time monitoring result

According to the standard, a CO_2 level range between 1000-1150 ppm is considered acceptable in college and university classrooms. In our case, the CO_2 level inside the classroom was below this threshold for most of the time. The buzzer, which indicates when CO_2 levels exceed 1150 ppm, only sounded twice during the monitoring period, as shown in Figure 12. This suggests that the ventilation rate was adequate to maintain good air quality throughout the monitoring period.

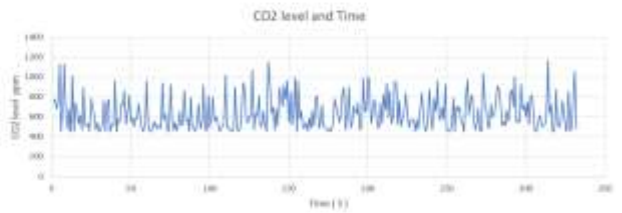

Fig. 12: CO_2 and time monitoring result

The standard noise level for primary and secondary classrooms is typically set in the range of 35-45 dB, while computer laboratories can go up to 50 dB, [17]. As shown in Figure 13, the sound levels in the ICA classroom ranged between 45-50 dB. While a noise level range of 40-50 dB might be acceptable in specific situations, it is generally considered less than ideal for maintaining optimal learning conditions. Since the classrooms regularly experience noise levels above this range, it may be beneficial to implement soundproofing measures or modify the classroom layout. Options such as acoustic panels, ceiling tiles, or even curtains can significantly reduce noise by absorbing sound waves and minimizing reverberation. These changes would create a quieter, more conducive learning environment.

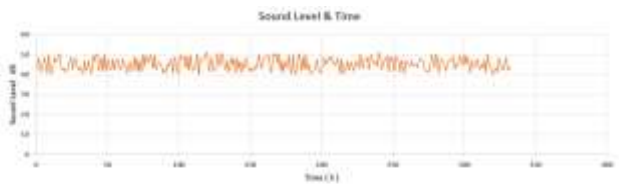

Fig. 13: Sound level and time monitoring result

4 Conclusion

Indoor Air Quality (IAQ) is a global priority to ensure healthy living and to monitor the effects of rising CO_2 levels and temperatures due to industrial growth and global warming. To address these concerns, a smart thermal environmental and noise monitoring system has been designed, built, and tested. The performance of this system was evaluated in a typical ICA classroom. The monitored parameters indicated that the hardware effectively maintained indoor quality conditions. Mechanical analysis of the classroom suggests that a 2-ton ceiling air conditioning unit is needed. This study highlights the effectiveness of an integrated sensor system in optimizing indoor conditions in educational environments. By seamlessly combining thermal comfort, indoor air quality (IAQ), and noise reduction, the system offers a comprehensive solution. The analysis of the monitored parameters confirms its high performance, effectively contributing to the maintenance and improvement of a comfortable and safe atmosphere in the ICA classroom.

Declaration of Generative AI and AI-assisted Technologies in the Writing Process

During the preparation of this work the authors used GPT4-o for language editing. After using this service, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

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